4-20-01

JC18 Rec'd PCT/PTO 20 APR 2001

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re of Applicant	)	
Shojiro KAWAKAMI et al.	)	Art Group: 09/762495 #4
Serial No.: 09/762,497	)	
Filing Date: February 7, 2001	)	
Accepted Date:	)	Examiner:
Title: POLARIZER	)	

Hon. Commissioner for Patents
Box: Missing Parts
Washington, D.C. 20231

RESPONSE TO NOTIFICATION OF MISSING REQUIREMENTS

Sir:

Responsive to the Notice to File Missing Parts dated March 15, 2001, Applicant submits the following:

REMARKS

Enclosed herewith please find the Executed Declaration, along with a check in the amount of Sixty-five Dollars ($65), for the late Declaration fee.

If the Examiner has any questions, the Examiner is invited to telephone the undersigned at (219) 485-6001.

04/25/2001 LLANDGRA 00000037 09762497
01 FC:254 65.00 OP

Respectfully submitted,

Randall J. Knuth
Registration No. 34,644

RJK/jrw

RANDALL J. KNUTH, P.C.
3510-A STELLHORN ROAD
FORT WAYNE, IN 46815-4631
Telephone: 219-485-6001
Facsimile: 219-486-2794

Enc.: Executed Declaration
Check No. 5175 ($65)
PCT/DO/EO/905 (copy)
PCT/DO/EO/917 (copy)

CERTIFICATE OF MAILING

I hereby certify that this correspondence is being deposited with the United States Postal Service as first class mail in an envelope addressed to: Commissioner of Patents and Trademarks, Washington, DC 20231, on April 16, 2001.

Randall J. Knuth, Reg. No. 34,644
Name of Registered Representative

Signature

April 16, 2001
Date

JC08 Rec'd PCT/PTO 07 FEB 2001

FORM PTO-1390 (REV 10-2000) U.S. DEPARTMENT OF COMMERCE PATENT AND TRADEMARK OFFICE

TRANSMITTAL LETTER TO THE UNITED STATES DESIGNATED/ELECTED OFFICE (DO/EO/US) CONCERNING A FILING UNDER 35 U.S.C. 371

ATTORNEY'S DOCKET NUMBER: FUK-81

U.S. APPLICATION NO. (If known, see 37 CFR 1.5): 09/762497

INTERNATIONAL APPLICATION NO.	INTERNATIONAL FILING DATE	PRIORITY DATE CLAIMED
PCT/JP99/04297	August 9, 1999	August 8, 1998

TITLE OF INVENTION: POLARIZER

APPLICANT(S) FOR DO/EO/US: Shojiro KAWAKAMI et al.

Applicant herewith submits to the United States Designated/Elected Office (DO/EO/US) the following items and other information:

1. [X] This is a **FIRST** submission of items concerning a filing under 35 U.S.C. 371.
2. [ ] This is a **SECOND** or **SUBSEQUENT** submission of items concerning a filing under 35 U.S.C. 371.
3. [ ] This is an express request to promptly begin national examination procedures (35 U.S.C. 371(f)).
4. [X] The US has been elected by the expiration of 19 months from the priority date (PCT Article 31).
5. [X] A copy of the International Application as filed (35 U.S.C. 371(c)(2))
   a. [ ] is attached hereto (required only if not communicated by the International Bureau).
   b. [X] has been communicated by the International Bureau.
   c. [ ] is not required, as the application was filed in the United States Receiving Office (RO/US).
6. [X] An English language translation of the International Application as filed (35 U.S.C. 371(c)(2)).
7. [X] Amendments to the claims of the International Application under PCT Article 19 (35 U.S.C. 371(c)(3))
   a. [ ] are attached hereto (required only if not communicated by the International Bureau).
   b. [ ] have been communicated by the International Bureau.
   c. [ ] have not been made; however, the time limit for making such amendments has NOT expired.
   d. [X] have not been made and will not be made.
8. [ ] An English language translation of the amendments to the claims under PCT Article 19 (35 U.S.C. 371(c)(3)).
9. [X] An oath or declaration of the inventor(s) (35 U.S.C. 371(c)(4)).
10. [ ] An English language translation of the annexes to the International Preliminary Examination Report under PCT Article 36 (35 U.S.C. 371(c)(5)).

Items 11 to 16 below concern document(s) or information included:

11. [X] An Information Disclosure Statement under 37 CFR 1.97 and 1.98.
12. [ ] An assignment document for recording. A separate cover sheet in compliance with 37 CFR 3.28 and 3.31 is included.
13. [X] A FIRST preliminary amendment.
    [ ] A SECOND or SUBSEQUENT preliminary amendment.
14. [X] A substitute specification.
15. [ ] A change of power of attorney and/or address letter.
16. [ ] Other items or information:

JC03 Rec'd PCT/PTO 07 FEB 2001

U.S. APPLICATION NO. (if known, see 37 CFR 1.5) 09/762497	INTERNATIONAL APPLICATION NO. PCT/JP99/04297	ATTORNEY'S DOCKET NUMBER FUK-81

17. ☒ The following fees are submitted:	CALCULATIONS	PTO USE ONLY
BASIC NATIONAL FEE (37 CFR 1.492 (a) (1) - (5)):		
Neither international preliminary examination fee (37 CFR 1.482) nor international search fee (37 CFR 1.445(a)(2)) paid to USPTO and International Search Report not prepared by the EPO or JPO **$1000.00**		
International preliminary examination fee (37 CFR 1.482) not paid to USPTO but International Search Report prepared by the EPO or JPO....... **$860.00**		
International preliminary examination fee (37 CFR 1.482) not paid to USPTO but international search fee (37 CFR 1.445(a)(2)) paid to USPTO **$710.00**		
International preliminary examination fee paid to USPTO (37 CFR 1.482) but all claims did not satisfy provisions of PCT Article 33(1)-(4) **$690.00**		
International preliminary examination fee paid to USPTO (37 CFR 1.482) and all claims satisfied provisions of PCT Article 33(1)-(4) **$100.00**		
ENTER APPROPRIATE BASIC FEE AMOUNT =	$ 860.00	
Surcharge of **$130.00** for furnishing the oath or declaration later than ☐ 20 ☐ 30 months from the earliest claimed priority date (37 CFR 1.492(e)).	$ --00--	

CLAIMS	NUMBER FILED	NUMBER EXTRA	RATE		
Total claims	4 - 20 =	0	X **$18.00**	$ --00--	
Independent claims	3 - 3 =	0	X **$80.00**	$ --00--	
MULTIPLE DEPENDENT CLAIM(S) (if applicable)			+ **$270.00**	$ --00--	
TOTAL OF ABOVE CALCULATIONS =				$ 860.00	
☒ Applicant claims small entity status. See 37 CFR 1.27. The fees indicated above are reduced by 1/2.				$ 430.00	
SUBTOTAL =				$ 430.00	
Processing fee of **$130.00** for furnishing the English translation later than ☐ 20 ☐ 30 months from the earliest claimed priority date (37 CFR 1.492(f)). +				$ --00--	
TOTAL NATIONAL FEE =				$ 430.00	
Fee for recording the enclosed assignment (37 CFR 1.21(h)). The assignment must be accompanied by an appropriate cover sheet (37 CFR 3.28, 3.31). **$40.00** per property +				$ --00--	
TOTAL FEES ENCLOSED =				$ 430.00	
				Amount to be refunded:	$
				charged:	$

a. ☒ A check in the amount of $ 430.00 to cover the above fees is enclosed. Check No. 5018

b. ☐ Please charge my Deposit Account No. ________ in the amount of $________ to cover the above fees. A duplicate copy of this sheet is enclosed.

c. ☒ The Commissioner is hereby authorized to charge any additional fees which may be required, or credit any overpayment to Deposit Account No. 501157. A duplicate copy of this sheet is enclosed.

NOTE: Where an appropriate time limit under 37 CFR 1.494 or 1.495 has not been met, a petition to revive (37 CFR 1.137(a) or (b)) must be filed and granted to restore the application to pending status.

SEND ALL CORRESPONDENCE TO:

CUSTOMER NO. 22855

22855

PATENT TRADEMARK OFFICE

Telephone: 219-485-6001
Facsimile: 219-486-2794

SIGNATURE:

Randall J. Knuth

NAME

34,644

REGISTRATION NUMBER

"EXPRESS MAIL" COVER LETTER

09/762497

JC03 Rec'd PCT/PTO 07 FEB 2001

Date: February 7, 2001

Commissioner of Patents and Trademarks
Box: PCT
Washington, DC 20231

Re: National Stage PCT Application for United States Letters Patent
APPLICANT: Shojiro KAWAKAMI et al.
TITLE OF INVENTION: POLARIZER

Sir:

Forwarded herewith is the above-identified application, consisting of the following:

PTO-1390
Substitute Specification (16 Sheets)
Preliminary Amendment (3 Sheets) accompanied by
Clean Claims (2 Sheets)
Replacement Abstract of the Disclosure
Verification of Translation and Translated Application (21 Sheets)
Drawings (6 Sheets)
Unexecuted Declaration
Applicant claims small entity status. See 37 CFR 1.27.
Information Disclosure Statement
Form PTO-1449
Cited Art References

Respectfully submitted,

Randall J. Knuth
Registration No. 34,644

RJK/jrw
Enclosures: As stated above.
Check No. 5018 ($430)
Return Postcard

RANDALL J. KNUTH, P.C.
3510-A STELLHORN ROAD
FORT WAYNE, IN 46815-4631
TELEPHONE: 219-485-6001
FACSIMILE: 219-486-2794

"EXPRESS MAIL" Mailing Number EL161762905US
Date of Deposit February 7, 2001.

I hereby certify that this paper or fee is being deposited with the United States Postal Service "EXPRESS MAIL POST OFFICE TO ADDRESSEE" service under 37 CFR 1.10 on the date indicated above and is addressed to the Commissioner of Patents and Trademarks, Washington, DC 20231

Randall J. Knuth, Registration No. 34,644
(Typed Name of Person Mailing Paper or Fee)

(Signature of Person Mailing Paper or Fee)

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re Application of	)	
Shojiro KAWAKAMI et al.	)	Group:
Serial No.:	)	
Filed: February 7, 2001	)	Examiner:
Title: POLARIZER	)	

PRELIMINARY AMENDMENT

Hon. Commissioner of Patents and Trademarks
Washington, D.C. 20231

Sir:

Applicant hereby submits the following Amendment.

IN THE CLAIMS

1. (Amended) A polarizer [which has the] comprising:

a multilayered structure along z-axis consisting of two or more transparent bodies which have different refractive indexes[,];

wherein the shape of layers which is the unit of lamination of each transparent body has a regularly undulated structure along the x-axis, is uniform along the y-axis, or has regularly or non-regularly undulated structure which is larger than the x-axis[, and has]; and

lamination along the z-axis repeating the shape, and acts against the light which has a component whose incidence direction is not zero from the z-axis in the three-dimensional orthogonal coordinates (x, y, z).

2. (Amended) A polarized according to claim 1, wherein the polarizer has a more refractive medium layer containing one of Si

[or] <u>and</u> TiO_2 as a main component and a less refractive medium layer containing SiO_2 as a main component.

3. (Amended) A <u>method for producing a</u> polarizer [which was prepared by] <u>comprising the steps of:</u>

laminating a more refractive medium and a less refractive medium with <u>a</u> regularly repeating [the] shape by a film-forming method at least partly including the dry etching on a substrate which has <u>at least one of</u> regularly arranged grooves or regularly arranged linear projections or thin and long projections or thin and long grooves.

4. (Amended) A <u>method of producing a</u> polarizer [which was prepared by] <u>comprising the steps of:</u>

laminating a more refractive medium which contains <u>one of</u> Si or TiO_2 as a main component and a less refractive medium which contains SiO_2 as a main component with regularly repeating the shape by a film-forming method at least partly including the dry etching on a substrate which has <u>at least one of</u> regularly arranged grooves or regularly arranged linear projections or thin and long projections or thin and long grooves.

<u>IN THE ABSTRACT</u>

Please replace the abstract on file for the attached ABSTRACT OF THE DISCLOSURE.

If the Examiner has any questions or comments that would speed prosecution of this case, he is invited to call the undersigned at 219/485-6001.

Respectfully submitted,

Randall J. Knuth
Registration No. 34,644

RJK/jrw

Encs: Clean Claims
Replacement ABSTRACT OF THE DISCLOSURE

RANDALL J. KNUTH, P.C.
3510-A Stellhorn Road
Fort Wayne, IN 46815-4631
Telephone: 219/485-6001
Facsimile: 219/486-2794

"EXPRESS MAIL" Mailing Number EL161762905US

Date of Deposit February 7, 2001

I hereby certify that this paper or fee is being deposited with the United States Postal Service "EXPRESS MAIL POST OFFICE TO ADDRESSEE" service under 37 CFR 1.10 on the date indicated above and is addressed to the Commissioner of Patents and Trademarks, Washington, DC 20231

Randall J. Knuth, Registration No. 34,644
(Typed Name of Person Mailing Paper or Fee)

(Signature of Person Mailing Paper or Fee)

CLEAN CLAIMS AFTER PRELIMINARY AMENDMENT OF FEBRUARY 7, 2001

1. A polarizer comprising:

a multilayered structure along z-axis consisting of two or more transparent bodies which have different refractive indexes;

wherein the shape of layers which is the unit of lamination of each transparent body has a regularly undulated structure along the x-axis, is uniform along the y-axis, or has regularly or non-regularly undulated structure which is larger than the x-axis; and

lamination along the z-axis repeating the shape, and acts against the light which has a component whose incidence direction is not zero from the z-axis in the three-dimensional orthogonal coordinates (x, y, z).

2. A polarized according to claim 1, wherein the polarizer has a more refractive medium layer containing one of Si and TiO_2 as a main component and a less refractive medium layer containing SiO_2 as a main component.

3. A method for producing a polarizer comprising the steps of:

laminating a more refractive medium and a less refractive medium with a regularly repeating shape by a film-forming method at least partly including the dry etching on a substrate which has at least one of regularly arranged grooves or regularly

arranged linear projections or thin and long projections or thin and long grooves.

4. A method of producing a polarizer comprising the steps of:

laminating a more refractive medium which contains one of Si or TiO_2 as a main component and a less refractive medium which contains SiO_2 as a main component with regularly repeating the shape by a film-forming method at least partly including the dry etching on a substrate which has at least one of regularly arranged grooves or regularly arranged linear projections or thin and long projections or thin and long grooves.

ABSTRACT OF THE DISCLOSURE

A polarizer which has and regularly arranged two-dimensional structure which has a pitch of 1 mm or so or less. The polarizer has structure in which two or more film-shaped materials which have a substantially regularly arranged one-dimensional undulation. The polarizer also has a substantially regularly arranged two-dimensional structure. For example, the polarizer consist of materials 1 and 2 which have different refractive indexes. A regularly arranged two-dimensional structure which has a pitch of 1 mm or less can be obtained by a simple method. Because of this structure, the polarizer transmits the incident light which has a specific polarized plane and reflects the incident light which has a polarized plane which is orthogonal to the plane.

09/762497

JC03 Rec'd PCT/PTO 07 FEB 2001

SUBSTITUTE SPECIFICATION

Shojiro KAWAKAMI
Yasuo OTERA
Takayuki KAWASHIMA

POLARIZER

BACKGROUND OF THE INVENTION

1. Field of the invention.

The present invention relates to a polarizer for use in optical instruments utilizing the polarization phenomenon that is a property of the light, the polarizer permitting only the linearly polarized wave in a direction orthogonal thereto.

2. Description of the related art.

Polarizer is an element which transmits only the light component which vibrates to a specific direction among the non-polarized light or elliptically polarized light whose electric and magnetic field vibrates to non-specific directions to give the linearly polarized light. It is one of the most fundamental optical elements, and is widely used as a device for the optical communication, a pick-up for the optical disc, a liquid crystal display, optics-applying measurements, and so on. Operation modes of it can be roughly grouped into the following two modes: 1) the mode in which unnecessary polarized waves are absorbed, and 2) the mode in which two orthogonalized and polarized wave components which are emitted through the same light path are separated into different light paths. Depending on the purpose of utilizing a polarizer, the polarizer is required to have large aperture area, high performance, and so on or to be thin. It is

industrially important to be able to supply such a polarizer inexpensively.

Presently a polarizer is generally practically used which was prepared by doping a polymer film with a dichromic molecule such as iodine in the case of operation mode 1. Although this type of polarizer can be obtained inexpensively and in a large area, its extinction ratio and its temperature stability are low, i.e., it has these faults.

In order to solve those problems, a polarizer prepared with materials having high stability has been developed, i.e., a polarizer prepared by arranging to one direction an absorber such as metal and semiconductor in a transparent body such as glass in minute lines or thin films. Polarized wave components which are parallel to the minute lines or thin films are absorbed or reflected, and polarized waves which are orthogonal to them are transmitted. Although this type of polarizer can have a high extinction ration, steps such as cutting and polishing might be necessary, i.e., it is difficult to reduce the production cost. In addition, it is difficult to produce a thin polarizer which has a large area.

On the other hand, a polarizer which is prepared with double refraction single crystals for operation mode 2 is prepared by sticking two triangular prisms which are made of a material which has a large double refraction coefficient such as calcite. A typical one is made of Gran Thomson prisms. Although this type of polarizer can have generally a high extinction coefficient and

transmittance, it is difficult to produce a polarizer which has a large area or a thin one. The material is expensive, therefore the cost is high.

Polarizers utilizing the Brewster angle of a transparent body include a polarized beam splitter using a multilayer dielectric. Although it is inexpensive because it can be easily mass-produced, it has at least the following problems: high polarization is not obtained; miniaturization is difficult; and the wavelength band for use is narrow. Therefore, it is used only for limited purposes.

Each of the above-mentioned polarizers is practically used. On the other hand, very recently, a polarizer is theoretically proposed which utilizes an anisotropy of propagation property of a transparent body regularly arranged structure which has a pitch of the wavelength or shorter (Tetsuko Hamano, Masayuki Izutsu, and Hideki Hirayama, "Possibility of Polarizer Using Two-dimension Photonic Crystal," 58th Applied Physics Autumn Proceedings, paper 2a-W-7, 1977; Akira Sato and Masahiro Takebe "Optically Anisotropic Multilayered Film by Structural Double Refraction," Optics Japan '97 Proceedings, paper 30pD01, 1997). These polarizers have the structure in which thin pillars of a transparent body which has a refractive index which is different from the matrix are arranged two-dimensionally and regularly in a transparent matrix. If the structure satisfies a condition that the pitch is, for example, half-wave length or so, among polarized waves which are parallel and vertical to those pillars,

one can be transmitted, and the other can be blocked, i.e., it can work as a polarizer. Actually, however, any method for industrially constructing such structure has not been found, and any experimental example has not been reported.

The present invention was conceived to solve the above-mentioned problems. The object of the present invention is to provide a polarizer which has an excellent extinction ratio and insertion loss property and has a large aperture area in spite of a small optical path length, and allows inexpensive industrial production.

SUMMARY OF THE INVENTION

Background technologies concerning the polarizer of the present invention will be described below. In an artificially and regularly arranged structure consisting of a more refractive medium and a less refractive medium, each of two polarized wave components which are orthogonal to each other has an independent dispersion relation (relation between frequency and wave motion vector). These two polarized wave components are called TE and TM waves depending on which, electric field or magnetic field, is parallel to the longitudinal direction in the two-dimensionally and regularly arranged structure which is closely related to the present invention. Also in the general three-dimensionally and regularly arranged structure, inherent modes are normally grouped into TE-like and TM-like waves. Therefore, these waves are also designated TE and TM waves for convenience in the present invention. TE and TM waves have different band gaps each of

which is a frequency band at which the light is not transmitted. At a frequency band, one polarized mode may be blocked while another polarized mode may be a transmitted wave. Namely, at this frequency band, this regularly arranged structure can work as a polarizer which reflects or diffracts one polarized light and transmits another polarized light. In addition, a polarizer which has a sufficiently high extinction ratio is obtained by increasing a frequency.

The present invention is based on 1) the finding of the existence of properties of the plane-type polarizer in the structure which consists of two or more transparent bodies which have different refractive indexes, wherein the shape of the layer which is a unit of lamination has a regularly arranged structure along the x-axis, is uniform along the y-axis, or has a longer pitch than along x-axis, and each layer is laminated along z-axis keeping each shape, in the three-dimensional rectangular coordinate system (x, y, z), i.e., in the structure in which two or more thin films which have regularly arranged pleats, or undulation, are laminated, and 2) the finding of the method for constructing the regularly arranged structure which the applicants have developed. The light is emitted vertically or slantwise to the plane. The aperture area depends on the size of the substrate, so that it is quite easy to enlarge the aperture area. On the other hand, although the optical path length is several times of the wavelength (several mm) or so, so that the

polarizer according to the present invention can be approximately 10^{-n} (n= -) times thinner than conventional polarizers.

On the other hand, in the method for forming a film using both the diffusion incidence of depositing particles which is represented by both bias spattering and spatter-etching, it is possible to laminate with repeating the undulation of the surface by controlling each of the deposition and the etching. This mechanism can be explained by a combination at an appropriate ratio of the following three effects: 1) the effect in which the deposition rate is retarded in the concave part which becomes a shadow by the diffusion incidence of the depositing particles, (2) the effect in which the etching rate becomes the largest at a plane which gives a tilt angle between approximately 50°-60° in the spatter etching, and 3) the effect in which particles which were removed mainly by the spatter etching are reattached at other places (Shojiro Kawakami, Hisashi Sato, and Takayuki Kawashima, "Mechanism of Formation of 3D Regularly Arranged Nanostructure Which Is Prepared by the Bias Spattering Method," *The Transactions of the Institute of Electronics, Information and Communication Engineers* C-I, Vol.J81-C-I, no.2, pp. 108-109, Feb. 1998).

This technique allows regularly laminating thin films consisting of two transparent materials with regularly repeating undulation on a substrate on which rows of grooves are regularly arranged without laborious positioning. Namely, this technique

allows easily preparing the polarizer according to the present invention.

The present invention allows inexpensively providing a polarizer which has an excellent extinction ratio and insertion loss property, and/or has a large aperture area in spite of a small optical pass length.

BRIEF DESCRIPTION OF THE DRAWINGS

The above-mentioned and other features and advantages of this invention, and the manner of attaining them, will become more apparent and the invention will be better understood by reference to the following description of an embodiment of the invention taken in conjunction with the accompanying drawings, wherein:

Fig. 1 illustrates the structure of a polarizer of Example 1;

Fig. 2 illustrates a substrate which has grooves on its surface;

Fig. 3a illustrates the intensity distribution of the transmitted light to TE wave in the near view;

Fig. 3b illustrates the intensity distribution f the transmitted light to TM wave in the near view;

Fig. 4 illustrates the relation between the frequency and the wave motion vector in Example 1;

Fig. 5 illustrates the structure of a polarizer of Example 2; and

Fig. 6 illustrates the relation between the frequency and the wave motion vector in Example 2.

Corresponding reference characters indicate corresponding parts throughout the several views. The exemplification set out herein illustrates one preferred embodiment of the invention, in one form, and such exemplification is not to be construed as limiting the scope of the invention in any manner.

DETAILED DESCRIPTION OF THE INVENTION

Explanation of Reference Numerals

1	SiO_2 layer	5	Regularly arranged grooves
2	Si layer	6	A frequency band at which a polarizer transmits TM wave
3	Substrate		
4	Non-reflecting coating layer	7	SiO_2 layer
		8	Si layer

Fig. 1 illustrates a polarizer according to the present invention. A polarizer according to the present invention will be described referring to Fig. 1 below.

A transparent medium which has a higher refractive index and a transparent medium which has a lower refractive index are alternately laminated on regularly arranged grooves or rows of linear injections keeping the shape of the interface. Polarizers in the following examples have regular arrangement along x- and z-axes, and are uniform along y-axis. The operation mechanism is similar even if the structure is changed to have regularly or non-regularly arranged structure which has a length larger than x-axis. To the regularly arranged structure thus obtained, non-

polarized or elliptically polarized light is emitted along z-axis. To polarized wave parallel to the groove row (y-polarized wave) and polarized wave orthogonal to the wave (x-polarized wave), TE mode and TM mode lights are generated in the regularly arranged structure. If the frequency of the light is in the TE mode and TM mode band gap, however, the mode can not be transmitted in the regularly arranged structure, so that the emitted light is reflected or diffracted. On the other hand, the frequency of the light is in the energy band, the light is transmitted in the regularly arranged structure keeping the wave motion vector. Therefore, it works as a plane-type polarizer.

The wave length band at which TE mode and TM mode band gaps are generated can be arbitrarily changed by controlling the pitch of the groove row (Lx) and the pitch of the direction of the lamination (Lz) of the polarizer according to the present invention. Namely, it is possible to arbitrarily set the wavelength band at which the polarizer works.

In addition, as a less refractive medium, a material containing SiO_2 as a main component is most popularly used. SiO_2 has a broad transparent wavelength region, is stable chemically, thermally, and mechanically, and allows easy formation fo a film. As a more refractive material an oxide such a TiO_2 and the like have a broad transparent wavelength range, so that they can be used also in a visible light region. On the other hand, although the semiconductor is used only in a near infrared region, it has an advantage of a large refractive index.

It is desirable that the polarizer for many purposes can be used in a broad frequency band. A broad frequency band for the polarizer can be taken by appropriately determining the shapes of the more refractive medium layer and the less refractive medium layer. The degree of freedom in the shapes of the more refractive medium layer and the less refractive medium layer is large for monochromic light such as specific laser light, so that the shape can be selected which allows easy repeat in forming film.

Shapes of layers and repeating structure, and methods for preparing them will b described in the following examples.

<u>Example 1</u>.

Fig. 1 illustrates the structure of a polarizer of Example 1. Fig. 1 illustrates amorphous SiO_2 layer 1 and amorphous Si layer 2. A pitch along x-axis (Lx) is 0.4 mm, and a pitch along z-axis (Lz) is 0.32 mm. SiO_2 and SiO layers have shapes which were regularly bent with slightly changing thickness "t". A method for preparing the polarizer will be described below. First, regularly arranged grooves were prepared on a substrate by the electric beam lithography and the dry etching. Fig. 2 illustrates quartz glass substrate 3, non-reflecting coating layer 4, and regularly arranged groove part 5. Although non-reflecting coating layer 4 and regularly arranged groove part 5 are generally selected from the substrate depending on the dimension of the regularly arranged structure, they can be the same material as the substrate. The latter case is provided in

the example. The width of the groove is 0.4mm, the depth of the groove is 0.2mm, and the pitch of the groove to the horizontal direction is 0.4 mm. On this substrate, SiO_2 and Si layers were alternately laminated using targets of SiO_2 and Si by the bias spattering method. It is important to form films keeping regularly undulated form along the x-axis of each layer. The condition was as follows: To form a film of SiO_2 , and Ar gas pressure of 1.9 mTorr, a target high frequency electric power of 400W, and substrate high frequency electric power of 60W. To form a film of Si, and Ar gas pressure of 3.6 mTorr and a target high frequency electric power of 400W. Ten SiO_2 layers and ten Si layers were laminated.

The reason why the laminated structure shown by Fig. 1 is formed on the substrate which has rectangular grooves shown by Fig. 2 under the condition can be explained by a combination of two or more phenomena selected from the following three phenomena: 1) deposition by dispersion incidence of neutral particles from the target, 2) spatter etching by vertical incidence of Ar ion, and 3) the reattachment of deposited particles.

Figs. 3a and 3b illustrate an intensity distribution of the transmitted light to TE and TM waves at a wavelength of 1.0 mm in the near view in the regularly arranged structure which was thus obtained. The abscissa is the position on a substrate wafer. The central part is a polarizer part. On both sides of the part, the substrate wafer does not have any groove, and parallel layers

of Si and SiO_2 were deposited. The ordinate is the strength of transmitted light at each point on a substrate wafer. It might be easily understood that the polarizer part substantially blocked TE wave. On the other hand, for TM wave, the difference is minute between the intensity of te transmitted light in the film part which were deposited on a substrate which has no groove on both sides and that of the polarizer part. In other words, TM wave can be transmitted with minute loss by applying a non-reflecting coating on a polarizer part.

Fig. 4 illustrates the relation between the frequency and the wave motion vector in the regularly arranged structure as calculated by the FDTD method (Finite Difference Time Domain method) using the regularly arranged boundary condition. The analysis of the band structure and light transmission properties of a photonic crystal by the FDTD method was reported by S. Fan et al. (Physical Review B, vol. 54, no. 16, pp. 11245-11251 (1996)). In Fig. 4, the abscissa is a relative value of a magnitude of the wave motion vector, and the ordinate is a relative value of frequency Lx/1, wherein 1 is a wavelength of the emitted light, and kz is a z-component of the wave motion vector. The solid and dashed lines are dispersion curves in TE and TM waves, respectively. Lx = 0.4 mm and 1 = 1 mm give a frequency (Lx/1) of 0.4. As understood from Fig. 4, the line Lx/1 = 0.4 does not cross the dispersion curve of TE wave (solid line), but crosses the dispersion curve of TM wave (dashed line). This means that TE wave is blocked/reflected, and that TM wave is

transmitted. Namely this regularly arranged structure works as a polarizer which transmits TM wave in a frequency band 6 which has a frequency (Lx/1) of 0.39 to 0.43.

Example 2.

This example will illustrate that a polarizer is obtained which has excellent properties even if parameters such as the uniformity of the thickness of the layer of each dielectric band in the plane, the shape of grooves, and an Lz-Lx ratio are different from those of Example 1.

Fig. 5 illustrates the constitution fo other examples of the present invention including amorphous SiO_2 layer 7 and amorphous Si layer 8. A pitch along x-axis (Lx) is 0.4 mm, and a pitch along z-axis (Lz) is 0.32 mm. This polarizer has the structure in which SiO_2 and Si layers are regularly bent changing the thickness of the SiO_2 layer between 0.9 Lz and 0.3 Lz, and changing the thickness of Si layer between 0.1 Lz and 0.7 Lz. To prepare the laminated films, although the same substrate was used as that of Example 1, a different condition was used for bias spattering for forming SiO_2 and Si layers.

Fig. 6 illustrates the relation between the frequency and the wave motion vector in this regularly arranged structure as calculated by the FDTD method. The abscissa is a relative magnitude of the wave motion vector, and the ordinate is a relative frequency. The solid and dashed lines are dispersion curves in TE and TM waves. As understood from Fig. 6, this polarizer has a wider frequency band to work as a polarizer than

that of Example 1. It is preferable that the frequency width is wide also for a polarizer which is sued at a single frequency of light with respect to one band gap. Because at a frequency which is not sufficiently distant from the end of the band gap, the frequency along z-axis which is necessary to take a sufficiently large extinction ratio increases.

In Examples 1 and 2, although a ratio of the pitch along z-axis and that of x-axis (Lz/Lx) is 0.8, from other calculations by the FDTD method, it is known that the polarizer works even at a ratio of approximately 0.2. Although the pitch along x-axis (lx) is selected to be a wavelength of the light or less when used as a normal polarizer, it is known that it is better to select a pitch (lx) which is longer than the wavelength of the light for a polarizing element which transmits one polarized light and diffracts the other polarized light. It is also known from other calculations that grooves need not be uniform along the y-axis, can have a different regularly arranged structure with respect to the width and gap of grooves along the x-axis, or can have random lengths which are sufficiently long along the y-axis.

Although the bias spattering method was used as a means to repeatedly laminate unit layers in this example, the degree of freedom in designing the shape of the unit layer of the lamination can be enhanced by adding a method of performing the deposition process and the spattering process non-simultaneously. As a less refractive medium, optical glass such as Pyrex glass

can be used as will as amorphous SiO_2. As a more refractive medium, TiO_2, TaO_2O_5, and the like can be used as will as Si. The cross-sectional shape of the groove of the substrate can be rectangular as well as V-shaped. Various shapes of cross-section of groove can be formed by appropriately selecting the condition fo bias spattering.

In order to use laminated films which were thus prepared as a polarizer, non-reflecting coatings are applied on the surface and the plane which is opposite to the substrate, and the obtained films are cut. Many elements can be prepared in a batch. In addition, polishing is not necessary, and cutting process is simple. As a result, polarizers can be provided inexpensively. The thickness of laminated films excluding substrate is several micrometers, so that the polarizer can be used with vertical incidence or with a small incidence angle. Therefore, wide application is possible as a small isolator for optical communication and so on. When the polarizer is used a polarized light-separating element for an optical circulator and so on, the polarizer might be used being inclined much to the incident light. Even in such a case, the light does not transmit the section, so that polishing is not necessary.

A polarizer which is prepared by film-forming method including spattering-etching action according to the present invention has a minute thickness along the direction of transmission of the light, and can be prepared as large laminated films in one film-forming process. Polishing is not necessary

and cutting is easy when each is prepared. It is possible to design a polarizer which has excellent polarization properties corresponding to a wavelength region to be used. Such a polarizer is most suitable for an optical isolator. Such a polarizer can be widely industrially used, for example, as an optical switch, and can be substituted for conventional polarizers.

While this invention has been described as having a preferred design, the present invention can be further modified within the spirit and scope of this disclosure. This application is therefore intended to cover any variations, uses, or adaptations of the invention using its general principles. Further, this application is intended to cover such departures from the present disclosure as come within known or customary practice in the art to which this invention pertains and which fall within the limits of the appended claims.

VERIFICATION OF A TRANSLATION

I, the below name translator, hereby declare that:

My name and post office address are as stated below;

That I am knowledgeable in the English language and in the language in which the below identified international application was filed, and that I believed the English translation of the international application PCT/JP99/04297 is a true and complete translation of the above-identified international application as filed.

I hereby declare that all statement made herein of my knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize validity of the application or any patent issued thereon.

Full name of the translator: Satoshi HOSHIKOSHI

Signature of the translator: Satoshi Hoshikoshi

Date: February 7, 2001

Post Office Address: 2nd floor, Fuji Building
5-11, Kudanminami 4-chome
Chiyoda-ku, Tokyo 102-0074
JAPAN

6/PRTS

09/762497

JC03 Rec'd PCT/PTO 07 FEB 2001

DESCRIPTION

POLARIZER

TECHNICAL FIELD

The present invention relates to a polarizer for use in optical instruments utilizing the polarization phenomenon that is a property of the light, the polarizer permitting only the linearly polarized light in a specific direction to be transmitted therethrough but reflecting the linearly polarized wave in a direction orthogonal thereto.

BACKGROUND ART

'Polarizer' is an element which transmits only the light component which vibrates to a specific direction among the non-polarized light or elliptically polarized light whose electric and magnetic field vibrates to non-specific directions to give the linearly polarized light. It is one of the most fundamental optical elements, and is widely used as a device for the optical communication, a pick-up for the optical disc, a liquid crystal display, optics-applying measurements, and so on. Operation modes of it can be roughly grouped into the following two modes: 1) the mode in which unnecessary polarized waves are absorbed, and 2) the mode in which two orthogonalized and polarized wave components which are emitted through the same light path are separated

into different light passes. Depending on the purpose of utilizing a polarizer, the polarizer is required to have large aperture area, high performance, and so on or to be thin. It is industrially important to be able to supply such a polarizer inexpensively.

Presently a polarizer is generally practically used which was prepared by doping a polymer film with a dichromic molecule such as iodine in the case of operation mode 1. Although this type of polarizer can be obtained inexpensively and in a large area, its extinction ratio and its temperature stability are low, i.e., it has these faults.

In order to solve those problems, a polarizer prepared with materials having high stability has been developed, i.e., a polarizer prepared by arranging to one direction an absorber such as metal and semiconductor in a transparent body such as glass in minute lines or thin films. Polarized wave components which are parallel to the minute lines or thin films are absorbed or reflected, and polarized waves which are orthogonal to them are transmitted. Although this type of polarizer can have a high extinction ratio, steps such as cutting and polishing might be necessary, i.e., it is difficult to reduce the production cost. In addition, it is difficult to produce a thin polarizer which has a large area.

On the other hand, a polarizer which is prepared

with double refraction single crystals for operation mode 2 is prepared by sticking two triangular prisms which are made of a material which has a large double refraction coefficient such as calcite. A typical one is made of Gran Thomson prisms. Although this type of polarizer can have generally a high extinction coefficient and transmittance, it is difficult to produce a polarizer which has a large area or a thin one. The material is expensive, so that the cost is high.

Polarizers utilizing Brewster angle of a transparent body include a polarized beam splitter using dielectric multilayer. Although it is inexpensive because it can be easily mass-produced, it has at least the following problems: high polarization is not obtained; miniaturization is difficult; and wavelength band for use is narrow. Therefore, it is used only for limited purposes.

Each of the above-mentioned polarizers is practically used. On the other hand, very recently, a polarizer is theoretically proposed which utilizes anisotropy of propagation property of transparent body regularly arranged structure which has a pitch of the wavelength or shorter (Tetsuko Hamano, Masayuki Izutsu, and Hideki Hirayama "Possibility of polarizer using two-dimensional photonic crystal" 58th Applied Physics Autumn Proceedings, paper 2a-W-7, 1977; Akira Sato and Masahiro Takebe "Optically anisotropic multilayered film

by structural double refraction" Optics Japan '97 Proceedings, paper 30pD01, 1997). These polarizers have the structure in which thin pillars of a transparent body which has a refractive index which is different from the matrix are arranged two-dimensionally and regularly in a transparent matrix. If the structure satisfies a condition that the pitch is, for example, half-wave length or so, among polarized waves which is parallel and vertical to those pillars, one can be transmitted, and the other can be blocked, i.e., it can work as a polarizer. Actually, however, any method for industrially constructing such structure has not been found, and any experimental example has not been reported.

The present invention was conceived to solve the above-mentioned problems. The object of the present invention is to provide a polarizer which has an excellent extinction ratio and insertion loss property and can has a large aperture area in spite of a small optical path length, and allows inexpensive industrial production.

DISCLOSURE OF THE INVENTION

Background technologies concerning the polarizer of the present invention will be described below. In artificially and regularly arranged structure consisting of a more refractive medium and a less refractive medium, each of two polarized wave components which are orthogonal to each other has an independent

dispersion relation (relation between frequency and wave motion vector). These two polarized wave components are called TE and TM waves depending on which, electric field or magnetic field, is parallel to the longitudinal direction in the two-dimensionally and regularly arranged structure which is closely related to the present invention. Also in the general three-dimensionally and regularly arranged structure, inherent modes are normally grouped into TE-like and TM-like waves. Therefore, these waves are also designated TE and TM waves for convenience in the present invention. TE and TM waves have different band gaps each of which is a frequency band at which the light is not transmitted. At a frequency band, one polarized mode may be blocked while another polarized mode may be a transmitted wave. Namely, at this frequency band, this regularly arranged structure can work as a polarizer which reflects or diffracts one polarized light and transmits another polarized light. In addition, a polarizer which has a sufficiently high extinction ratio is obtained by increasing a frequency.

The present invention is based on 1) the finding of the existence of properties of the plane-type polarizer in the structure which consists of two or more transparent bodies which have different refractive indexes, wherein the shape of the layer which is a unit of lamination has a regularly arranged structure along

x-axis, is uniform along y-axis, or has a longer pitch than along x-axis, and each layer is laminated along z-axis keeping each shape, in the three-dimensional rectangular coordinate system (x,y,z), i.e., in the structure in which two or more thin films which have regularly arranged pleats (undulation) are laminated, and 2) the finding of the method for constructing the regularly arranged structure which the applicants have been developed. The light is emitted vertically or slantwise to the plane. The aperture area depends on the size of the substrate, so that it is quite easy to enlarge the aperture area. On the other hand, although the optical path length depends on the lamination thickness, a sufficient optical path length is several times of the wavelength (several mm) or so, so that the polarizer according to the present invention can be approximately 10^{-n} (n= -) times thinner than conventional polarizers.

On the other hand, in the method for forming a film using both the diffusion incidence of depositing particles which is represented by both bias spattering and spatter-etching, it is possible to laminate with repeating the undulation of the surface by controlling each of the deposition and the etching. This mechanism can be explained by a combination at an appropriate ratio of the following three effects: 1) the effect in which the deposition rate is retarded in the concave part which becomes a shadow by the diffusion incidence of the

depositing particles, 2) the effect in which the etching rate becomes the largest at a plane which gives a tilt angle between approximately 50°-60° in the spatter etching, and 3) the effect in which particles which were removed mainly by the spatter etching are reattached to other places (Shojiro Kawakami, Hisashi Sato, and Takayuki Kawashima "Mechanism of formation of 3D regularly arranged nanostructure which is prepared by the bias spattering method" *The Transactions of the Institute of Electronics, Information and Communication Engineers* C-I, vol.J81-C-I, no.2, pp.108-109, Feb. 1998).

This technique allows regularly laminating thin films consisting of two transparent materials regularly repeating undulation on a substrate on which roes of grooves are regularly arranged without laborious positioning. Namely, this technique allows easily preparing the polarizer according to the present invention.

The present invention allows inexpensively providing a polarizer which has an excellent extinction ratio and insertion loss property, and/or has a large aperture area in spite of a small optical pass length.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 illustrates the structure of a polarizer of Example 1;

Fig. 2 illustrates a substrate which has grooves

on its surface;

Fig. 3a illustrates the intensity distribution of the transmitted light to TE wave in the near view;

Fig. 3b illustrates the intensity distribution of the transmitted light to TM wave in the near view;

Fig. 4 illustrates the relation between the frequency and the wave motion vector in Example 1;

Fig. 5 illustrates the structure of a polarizer of Example 2; and

Fig. 6 illustrates the relation between the frequency and the wave motion vector in Example 2.

(Explanation of Reference Numerals)

1 Si_2O layer

2 Si layer

3 Substrate

4 Non-reflecting coating layer

5 Regularly arranged grooves

6 A frequency band at which a polarizer transmits TM wave

7 SiO_2 layer

8 Si layer

BEST MODE FOR CARRYING OUT THE INVENTION

Fig. 1 illustrates a polarizer according to the present invention. A polarizer according to the present invention will be described referring to Fig. 1 below.

A transparent medium which has a higher refractive index and a transparent medium which has a lower

refractive index are alternately laminated on regularly arranged grooves or rows of linear injections keeping the shape of the interface. Polarizers in the following examples have regular arrangement along x- and z-axes, and are uniform along y-axis. The operation mechanism is similar even if the structure is changed to have regularly or non-regularly arranged structure which has a length larger than x-axis. To the regularly arranged structure thus obtained, non-polarized or elliptically polarized light is emitted along z-axis. To polarized wave parallel to the groove row (y-polarized wave) and polarized wave orthogonal to the wave (x-polarized wave), TE mode and TM mode lights are generated in the regularly arranged structure. If the frequency of the light is in the TE mode and TM mode band gap, however, the mode can not be transmitted in the regularly arranged structure, so that the emitted light is reflected or diffracted. On the other hand, the frequency of the light is in the energy band, the light is transmitted in the regularly arranged structure keeping the wave motion vector. Therefore, it works as a plane-type polarizer.

The wave length band at which TE mode and TM mode band gaps are generated can be arbitrarily changed by controlling the pitch of the groove row (Lx) and the pitch of the direction of the lamination (Lz) of the polarizer according to the present invention. Namely, it is possible to arbitrarily set the wavelength band at which

the polarizer works.

In addition, as a less refractive medium, a material containing SiO_2 as a main component is most popularly used. SiO_2 has a broad transparent wavelength region, is stable chemically, thermally, and mechanically, and allows easy formation of a film. As a more refractive material, an oxide such as TiO_2 and a semiconductor such as Si and GaAs can be used. TiO_2 and the like have a broad transparent wavelength range, so that they can be used also in a visible light region. On the other hand, although the semiconductor is used only in a near infrared region, it has an advantage of a large refractive index.

It is desirable that the polarizer for many purposes can be used in a broad frequency band. A broad frequency band for the polarizer can be taken by appropriately determining the shapes of the more refractive medium layer and the less refractive medium layer. The degree of freedom in the shapes of the more refractive medium layer and the less refractive medium layer is large for monochromic light such as specific laser light, so that the shape can be selected which allows easy repeat in forming film.

Shapes of layers and repeating structure, and methods for preparing them will be described in the following examples.

Example 1

Fig. 1 illustrates the structure of a polarizer of Example 1. Fig. 1 illustrates amorphous SiO_2 layer 1 and amorphous Si layer 2. A pitch along x-axis (Lx) is 0.4 mm, and a pitch along z-axis (Lz) is 0.32 mm. SiO_2 and SiO layers have shapes which were regularly bent with slightly changing thickness 't'. A method for preparing the polarizer will be described below. First, regularly arranged grooves were prepared on a substrate by the electric beam lithography and the dry etching. Fig. 2 illustrates quartz glass substrate 3, non-reflecting coating layer 4, and regularly arranged groove part 5. Although non-reflecting coating layer 4 and regularly arranged groove part 5 are generally selected from a material which is different from the substrate depending on the dimension of the regularly arranged structure, they can be the same material as the substrate. The latter case is provided in this example. The width of the groove is 0.4 mm, the depth of the groove is 0.2 mm, and the pitch of the groove to the horizontal direction is 0.4 mm. On this substrate, SiO_2 and Si layers were alternately laminated using targets of SiO_2 and Si by the bias spattering method. It is important to form films keeping regularly undulated form along x-axis of each layer. The condition was as follows: To form a film of SiO_2, an Ar gas pressure of 1.9 mTorr, a target high frequency electric power of 400W, and substrate high frequency electric power of 60W. To form a film of Si, an Ar gas

pressure of 3.6 mTorr and a target high frequency electric power of 400W. Ten SiO_2 layers and ten Si layers were laminate.

The reason why the laminated structure shown by Fig. 1 is formed on the substrate which has rectangular grooves shown by Fig. 2 under the condition can be explained by a combination of two or more phenomena selected from the following three phenomena: 1) deposition by dispersion incidence of neutral particles from the target, 2) spatter etching by vertical incidence of Ar ion, and 3) reattachment of deposited particles.

Figs. 3a and 3b illustrate an intensity distribution of the transmitted light to TE and TM waves at a wavelength of 1.0 mm in the near view in the regularly arranged structure which was thus obtained. The abscissa is the position on a substrate wafer. The central part is a polarizer part. On both sides of the part, the substrate wafer does not have any groove, and parallel layers of Si and SiO_2 were deposited. The ordinate is the strength of transmitted light at each point on a substrate wafer. It might be easily understood that the polarizer part substantially blocked TE wave. On the other hand, for TM wave, the difference is minute between the intensity of the transmitted light in the film part which were deposited on a substrate which has no groove on both sides and that of the polarizer part. In other words, TM wave can be transmitted with minute loss by applying a

non-reflecting coating on a polarizer part.

Fig. 4 illustrates the relation between the frequency and the wave motion vector in the regularly arranged structure as calculated by the FDTD method (Finite Difference Time Domain method) using the regularly arranged boundary condition. The analysis of the band structure and light transmission properties of a photonic crystal by the FDTD method was reported by S. Fan et al. (Physical Review B, vol. 54, no. 16, pp. 11245-11251 (1996)). In Fig. 4, the abscissa is a relative value of a magnitude of the wave motion vector, and the ordinate is a relative value of frequency Lx/1, wherein 1 is a wavelength of the emitted light, and kz is a z-component of the wave motion vector. The solid and dashed lines are dispersion curves in TE and TM waves, respectively. Lx = 0.4 mm and 1 = 1 mm give a frequency (Lx/1) of 0.4. As understood from Fig. 4, the line Lx/1 = 0.4 does not cross the dispersion curve of TE wave (solid line), but crosses the dispersion curve of TM wave (dashed line). This means that TE wave is blocked/reflected, and that TM wave is transmitted. Namely, this regularly arranged structure works as a polarizer which transmits TM wave in a frequency band 6 which has a frequency (Lx/1) of 0.39-0.43.

Example 2

This example will illustrate that a polarizer is obtained which has excellent properties even if

parameters such as the uniformity of the thickness of the layer of each dielectric band in the plane, the shape of groves, and an Lz/Lx ratio are different from those of Example 1.

Fig. 5 illustrates the constitution of other examples of the present invention including amorphous SiO_2 layer 7 and amorphous Si layer 8. A pitch along x-axis (Lx) is 0.4 mm, and a pitch along z-axis (Lz) is 0.32 mm. This polarizer has the structure in which SiO_2 and Si layers are regularly bent changing the thickness of SiO_2 layer between 0.9Lz and 0.3Lz, and changing the thickness of Si layer between 0.1Lz and 0.7Lz. To prepare the laminated films, although the same substrate was used as that of Example 1, a different condition was used for bias spattering for forming SiO_2 and Si layers.

Fig. 6 illustrates the relation between the frequency and the wave motion vector in this regularly arranged structure as calculated by the FDTD method. The abscissa is a relative magnitude of the wave motion vector, and the ordinate is a relative frequency. The solid and dashed lines are dispersion curves in TE and TM waves. As understood from Fig. 6, this polarizer has a wider frequency band to work as a polarizer than that of Example 1. It is preferable that the frequency width is wide also for a polarizer which is used at a single frequency of light with respect to one band gap. Because at a frequency which is not sufficiently distant from the end of the

band gap, the frequency along z-axis which is necessary to take a sufficiently large extinction ratio increases.

In Examples 1 and 2, although a ratio of the pitch along z-axis and that of x-axis (Lz/Lx) is 0.8, from other calculations by the FDTD method, it is known that the polarizer works even at a ratio of 0.2 or so. Although the pitch along x-axis (Lx) is selected to be a wavelength of th light or less or so when used as a normal polarizer, it is known that it is good to select a pitch (Lx) which is longer than the wavelength of the light for a polarizing element which transmits one polarized light and diffracts the other polarized light. It is also known from other calculations that grooves need not be uniform along y-axis, can have a different regularly arranged structure with respect to the width and gap of grooves along x-axis, or can have random lengths which are sufficiently long along y-axis.

Although the bias spattering method was used as means to repeatedly laminate unit layers in this example, the degree of freedom in designing the shape of the unit layer of the lamination can be enhanced by adding a method of performing the deposition process and the spattering process non-simultaneously. As a less refractive medium, optical glass such as Pyrex glass can be used as well as amorphous SiO_2. As a more refractive medium, TiO_2, Ta_2O_5, and the like can be used as well as Si. The cross-sectional shape of the groove of the substrate can be rectangular

as well as V-shape. Various shapes of cross-section of groove can be formed by appropriately selecting the condition of bias spattering.

In order to use laminated films which were thus prepared as a polarizer, non-reflecting coatings are applied on the surface and the plane which is opposite to the substrate, and the obtained films are cut. Many elements can be prepared in a batch. In addition, polishing is not necessary, and cutting process is simple. As a result, polarizers can be provided inexpensively. The thickness of laminated films excluding substrate is several micrometers, so that the polarizer can be used with vertical incidence or with a small incidence angle. Therefore, wide application is possible as a small isolator for optical communication and so on. When the polarizer is used as a polarized light-separating element for an optical circulator and so on, the polarizer might be used being inclined much to the incidence light. Even in such a case, the light does not transmit the section, so that polishing is not necessary.

INDUSTRIAL APPLICABILITY

A polarizer which is prepared by film-forming method including spattering-etching action according to the present invention has a minute thickness along the direction of transmission of the light, and can be prepared as large laminated films in one film-forming process. Polishing is not necessary and cutting is easy

when each element is prepared. It is possible to design a polarizer which has excellent polarization properties corresponding to a wavelength region to be used. Such a polarizer is most suitable for an optical isolator. Such a polarizer can be widely industrially used, for example, as an optical switch, and can be substituted for conventional polarizers.

WHAT IS CLAIMED IS:

1. A polarizer which has the multilayered structure along z-axis consisting of two or more transparent bodies which have different refractive indexes, wherein the shape of layers which is the unit of lamination of each transparent body has regularly undulated structure along x-axis, is uniform along y-axis, or has regularly or non-regularly undulated structure which is larger than x-axis, and has lamination along z-axis repeating the shape, and acts against the light which has a component whose incidence direction is not zero from z-axis in the three-dimensional orthogonal coordinates (x,y,z).

2. A polarizer according to claim 1, wherein the polarizer has a more refractive medium layer containing Si or TiO_2 as a main component and a less refractive medium layer containing SiO_2 as a main component.

3. A polarizer which was prepared by laminating a more refractive medium and a less refractive medium with regularly repeating the shape by a film-forming method at least partly including the dry etching on a substrate which has regularly arranged grooves or regularly arranged linear projections or thin and long projections or thin and long grooves.

4. A polarizer which was prepared by laminating a more refractive medium which contains Si or TiO_2 as a main component and a less refractive medium which contains SiO_2 as a main component with regularly repeating the shape by a film-forming method at least partly including the dry etching on a substrate which has regularly arranged grooves or regularly arranged linear projections or thin and long projections or thin and long grooves.

ABSTRACT

The present invention provides a polarizer which has and regularly arranged two-dimensional structure which has a pitch of 1 mm or so or less.

The polarizer has structure in which two or more film-shaped materials which have substantially regularly arranged one-dimensional undulation. The polarizer has substantially regularly arranged two-dimensional structure. For example, the polarizer consists of materials 1 and 2 which have different refractive indexes.

A regularly arranged two-dimensional structure which has a pitch of 1 mm or so or less can be obtained by a simple method. Because of this structure, the polarizer transmits the incidence light which has a specific polarized plane and reflects the incidence light which has a polarized plane which is orthogonalized to the plane.

09/762497

Fig.1

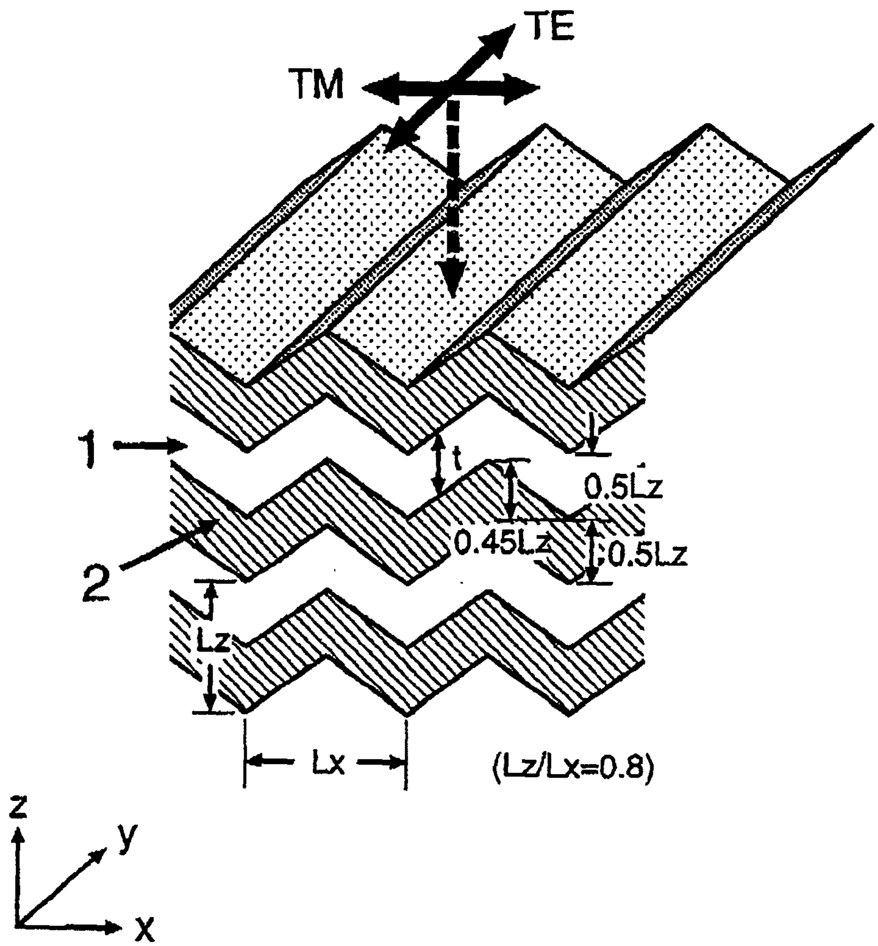


Fig.2

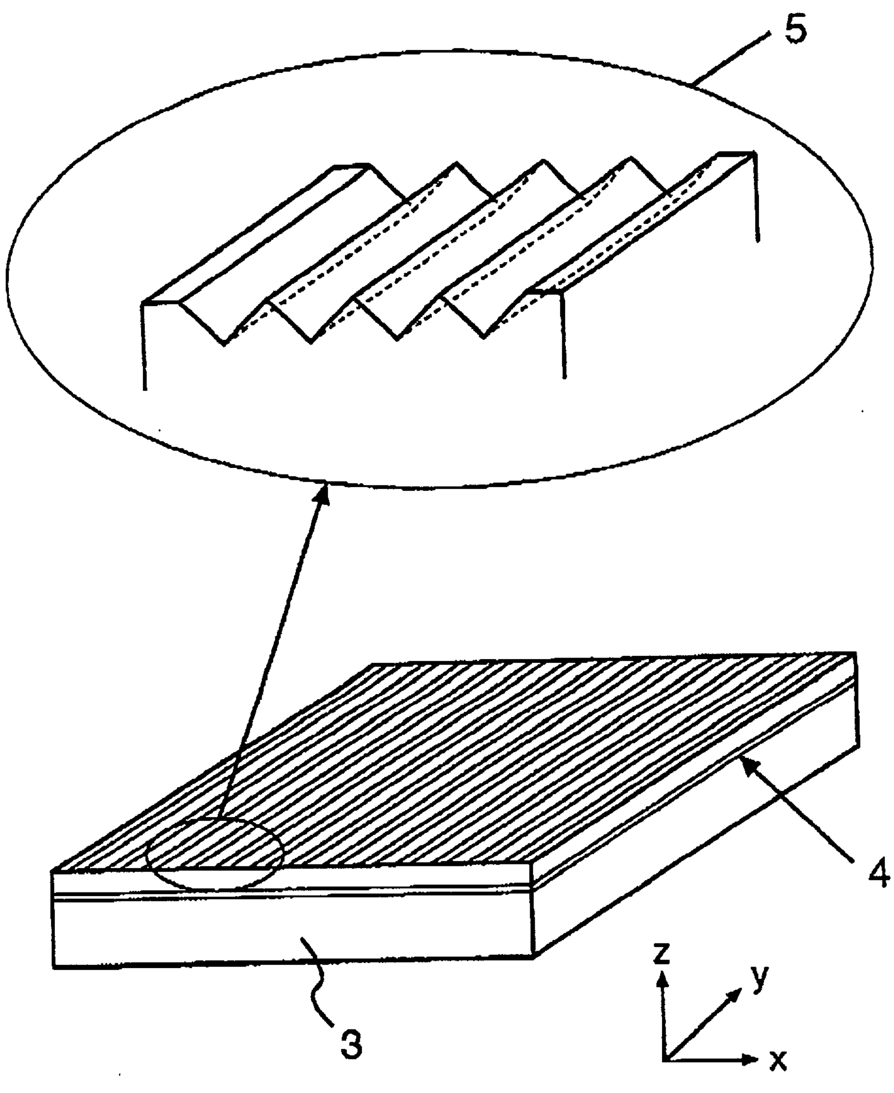
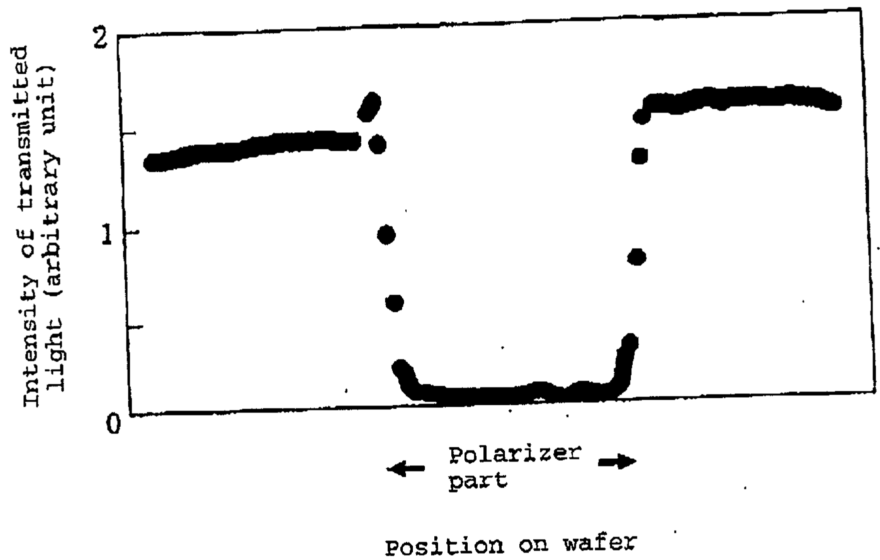
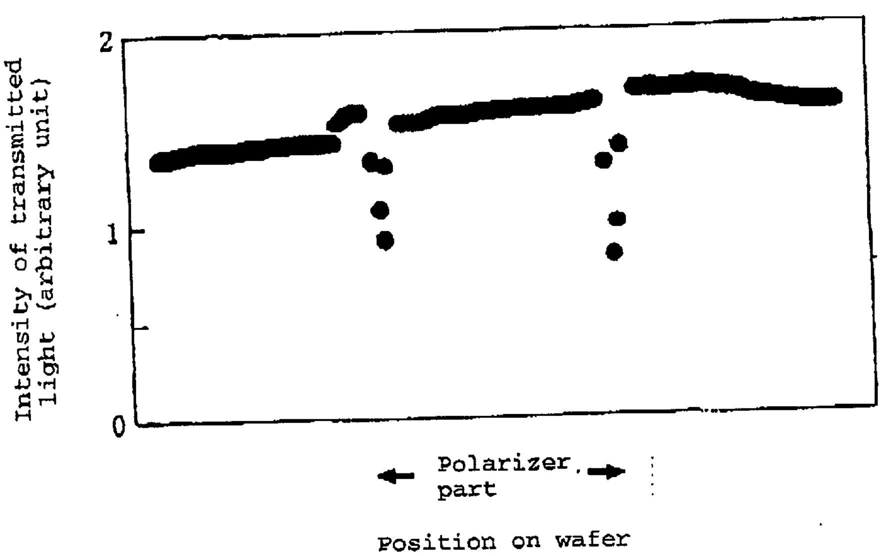


Fig.3

(a) TE wave

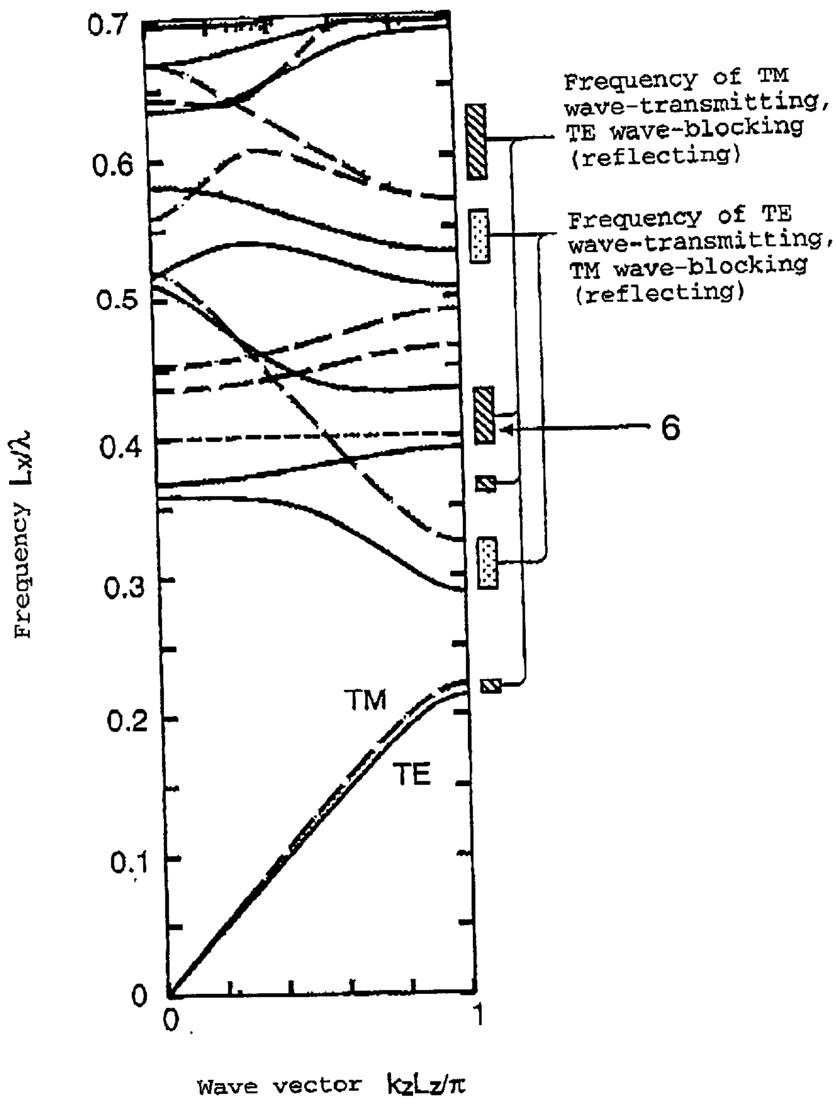


(b) TM wave



09/762497

Fig.4



09/762497

Fig.5

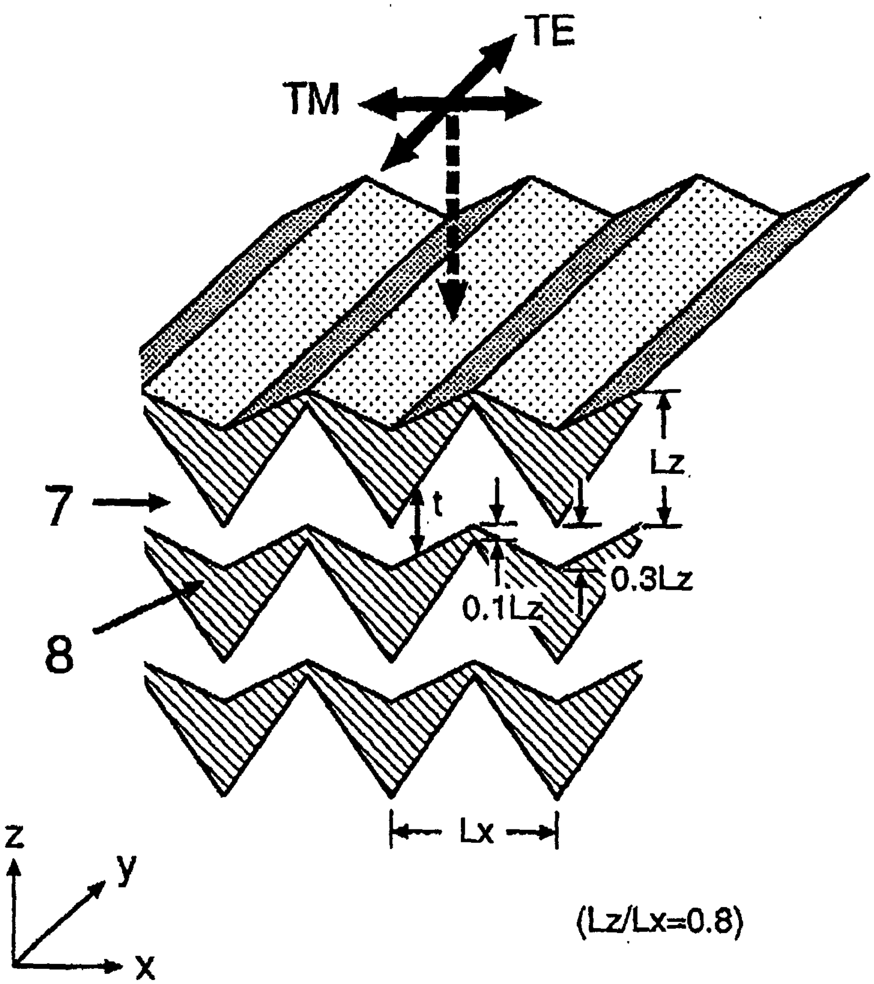
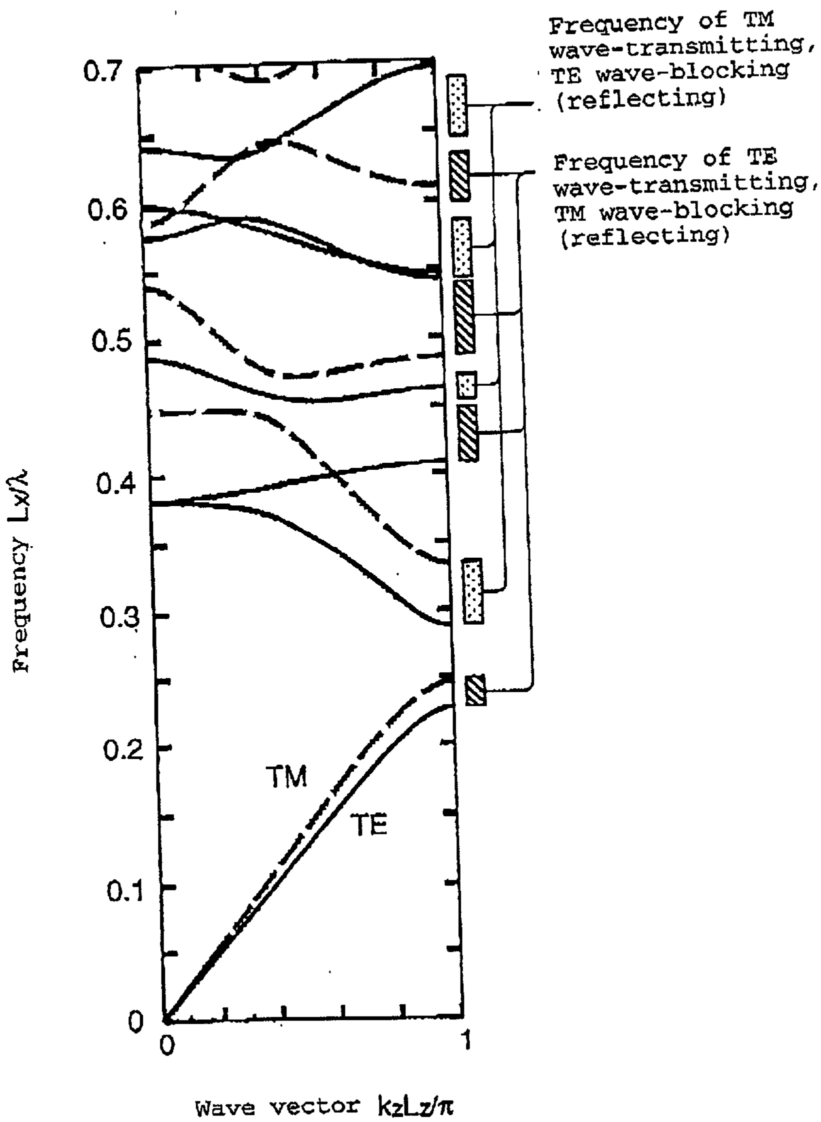


Fig.6


Frequency of TM wave-transmitting, TE wave-blocking (reflecting)
Frequency of TE wave-transmitting, TM wave-blocking (reflecting)
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Frequency Lx/λ
TM
TE
0
1
Wave vector kzLz/π

#4

ATTORNEY'S DOCKET NO. FUK-81

PCT/USA NATIONAL DECLARATION AND POWER OF ATTORNEY
FOR U.S. PATENT APPLICATIONS
IN THE UNITED STATES PATENT AND TRADEMARK OFFICE
UNDER 35 U.S.C. SECTION 371(c)(4)

As a below named inventor, we hereby declare that:
Our residence, post office address and citizenship are as stated below next to my name:
I verily believe I am the original, first and sole inventor (if only one name is listed below) or a joint inventor (if plural inventors are named below) of the invention described and claimed in International application No. PCT/JP99/04297 entitled: POLARIZER and as amended on ______________ (if any), which I have reviewed, and I understand the contents of the above identified specification, including the claims, as amended by any amendment referred to above and for which I solicit a patent; that I do not know and do not believe that this invention was ever known or used in the United States of America before my or our invention or discovery thereof, or patented or described in any printed publication in any country before my or our invention or discovery thereof, or more than one year prior to my international application; that this invention was not in public use or on sale in the United States of America for more than one year prior to my international application; that this invention has not been patented or made the subject of an inventor's certificate issued before the date of my international application in any country foreign to the United States of America on an application filed by me or my legal representatives or assigns more than twelve months before my international application; that I acknowledge my duty to disclose information of which I am aware which is material to the examination of this application; and that prior to filing said international application, applications for patent or inventor's certificate on this invention or discovery which have been filed by me or my legal representatives or assigns in any country foreign to the United States of America are as follows:

(a) none filed more than 12 months prior to said international application, unless named below:

(b) earliest filed less than 12 months prior to said international application (the priority of which is hereby claimed under 35 U.S.C. Section 365):

JP 10/257426 filed August 7, 1998

I hereby claim the benefit under Title 35, United States Code, §120, of any United States application(s) listed below and, insofar as the subject matter of each of the claims of this application is not disclosed in the prior United States application in the manner provided by the first paragraph of Title 35, United States Code, §112, I acknowledge the duty to disclose material information as defined in Title 37, Code of Federal Regulations, §1.56(a), which occurred between the filing date of the prior application and the national or PCT international filing date of this application.

(Application Serial No.)	(Filing Date)	(Status)(patented, pending, abandoned)

I hereby appoint Randall J. Knuth, Regis. No. 34,644 and Victor T. Lohmann, III, Regis. No. 33,951 of the firm of RANDALL J. KNUTH, P.C., as attorney(s) to prosecute this application and transact all business in the Patent and Trademark Office connected therewith.

I declare further that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

SEND CORRESPONDENCE TO:
Customer No. 22855

DIRECT TELEPHONE CALLS TO:
Randall J. Knuth, Esq.
Telephone: 219-485-6001
Facsimile: 219-486-2794

1-00 Full name of sole or first inventor: Shojiro KAWAKAMI

Residence Miyagi-ken JAPAN Citizenship Japanese JPX

Post Office Address Atagobashi Mansion Phareoh C-09, 236, Tsuchitoi, Wakabayashi-ku, Sendai-shi, Miyagi-ken 984-0065 JAPAN

Inventor's Signature Shojiro Kawakami Date April 10, 2001

ATTORNEY'S DOCKET NO. FUK-81

2-00

Full name of second inventor: Yasuo OTERA

Residence: Miyagi-ken JAPAN Citizenship Japanese JPX

Post Office Address Corpo-Kaneko 201, 6-15, Tsuchitoi 1-chome, Aoba-ku, Sendai-shi, Miyagi-ken 980-0065 JAPAN

Inventor's Signature Yasuo Otera Date April 10, 2001

3-00

Full name of third inventor: Takayuki KAWASHIMA

Residence: Miyagi-ken JAPAN Citizenship Japanese JPX

Post Office Address Le village 203, 45-5, Kawauchi-Samjuninmachi, Aoba-ku, Sendai-shi, Miyagi-ken 980-0866 JAPAN

Inventor's Signature Takayuki Kawashima Date April 10, 2001